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TERRAIN ANALYSIS IN MOBILITY STUDIES FOR MILITARY VEHICLES

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Defence Research Board of Canada
Contract VC 69-500007
Serial No. 2VC 5-1

First printed in *Land Evaluation*, edited by G. A. Stewart, Macmillan Company of Australia, 1968, and reproduced by permission of the publishers.

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Terrain Analysis in Mobility Studies for Military Vehicles

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The terrain analysis system developed at McGill University has been applied in the military training area of Camp Petawawa, Ontario. The study was undertaken to determine the potential of large-scale air photographs (1 : 5000) in assessing the specific environmental factors which affect the cross-country mobility of military vehicles. Surface composition, macromorphology, micromorphology, and surface cover were considered, and map overlays prepared for each factor.

Tests in the area indicated that vehicle performance was similar for areas with similar arrays of terrain characteristics and on this basis successful predictions of speed were made for cross-country test runs traversing a variety of terrain units.

Data storage and retrieval are very serious problems in any terrain classification system. Two approaches to this general problem were investigated: the unit land form approach and the computer map approach. In the former, the ground surface is treated as a mosaic and small landscape units are outlined. Each of these is uniform with respect to surface composition and macromorphology. The other attributes of the unit are recorded by an array of symbols. The total composite map of this type amounts to a data storage bank.

The second approach is a simple computer mapping programme in which the lines and rows of the computer page are used as rectangular co-ordinates for the area and the terrain data cards are keyed to this grid. The map output can show single factors, associations of factors, or go–no go conditions for particular vehicles.

In 1967 the terrain analysis system developed at McGill University[1] was applied in a small area of eastern Canada—the Canadian Forces Base at Petawawa, which lies in the Ottawa valley about 80 miles north-west of Ottawa. The camp is only 30 sq miles in area, but it includes quite varied conditions, and a small area was mandatory because the study was designed to investigate three basic problems:

1. Since air photo interpretation has been the main source of terrain information for some time, and will probably remain so in the immediate future, a careful evaluation of the quanta of terrain information which can be extracted from large-scale air photos (1:5000) was attempted. It is seldom possible to obtain vertical air photo coverage of any considerable area at scales larger than 1:5000, and so photos at this scale may be considered as the optimum information source for this type of remote sensing. In order to test the interpretation procedures, the terrain analysis of the camp area was completed with a minimum of on-site information.

[1]The research for this project was undertaken at the Department of Geography, McGill University, for the Defence Research Board of Canada – Contract VC 69-500007 – Serial No. 2VC 5-1.

2. Data storage, retrieval, and display constitute a major problem area, and so some experimentation with suitable output forms was attempted.
3. In order to test the validity of the system as a whole it was decided that vehicle performance figures should be obtained for as many different terrain units as possible. Without this kind of test there is no way of knowing whether the terrain differences which appear at the interpretation stage are truly significant or not.

SIGNIFICANT TERRAIN FACTORS AND AIR PHOTO INTERPRETATION

The terrain at any locality is a complex of interacting factors. Not all factors affect ground mobility either directly or indirectly, and the first problem is to isolate those that are significant. Our work shows broad agreement with the studies undertaken at the Waterways Experiment Station (U.S.A.E.) in distinguishing the terrain factors significant in cross-country mobility. Four basic factors have been identified: surface composition, surface morphology including both macromorphology and micromorphology, surface cover including man-made features and vegetation, and surface climate. With the exception of the climatic factor, which demands an entirely different approach, it is possible to obtain a considerable amount of information about all the terrain factors by non-contact methods, such as air photo interpretation. For this reason, the climatic factor was not considered in the Petawawa study, although it is recognised that the local climate exercises an important control on the state of the ground, and thus on all types of surface movement. The other factors were assessed in turn and mapped at a scale of 1:25,000—each factor map being in the form of a coloured transparency, designed for use either singly, or in combination, as an overlay on a photo mosaic of the area.

The production of the factor maps involved the adoption of suitable classification systems, which will be discussed in each of the following sections, and then the application of the system by air photo interpretation. The basic interpretation procedure is that of discrimination – areas or groups of objects which appear to have a separate individuality are recognised, and boundary lines drawn separating one from another. Some terrain factors are directly visible on the air photo, but others are not, and in these cases the classification of surface conditions within the delineated areas depends on the extent to which indirect evidence provides a convergence towards a particular identification.

Surface Composition

The surface composition is the most fundamental of the terrain factors because it determines the load which can be supported at a particular site, and the tractive forces which can be applied. Surface composition varies considerably: in mechanical terms the range is from a rigid elastic solid – consolidated rock – to a Newtonian fluid – water. Because of the tremendous variation in surface composition, even within a particular mechanical class, it is necessary to adopt specific classification systems for each surface type. The specific classification systems indicated in Table 1 were chosen from the existing systems because they are based on factors which have a direct bearing upon the trafficability of the material, and because they can be applied in both contact and non-contact situations.

The photo interpretation of surface composition at Camp Petawawa proved

to be fairly straightforward, since only a few composition types were involved and discrimination and identification were relatively easy. Some information on the surface composition was derived from published sources (Gillespie 1964; Gadd 1963); however, the plotting of the boundaries was based entirely on photo interpretation, and subsequent field checking showed that the accuracy was good. The major limiting factor was the obscuring effect of the vegetation, which resulted in the failure to identify several small rock outcrops and water bodies.

TABLE 1

Surface composition

Major Composition Type		Specific Classification System
Rigid elastic solids	Consolidated crystalline and sedimentary rocks	Miles system (Miles 1963)
Non-rigid solids in region of elastic behaviour	Unconsolidated rudaceous and arenaceous rocks	Miles system (Miles 1963)
	Frozen ground	*
Plastic and visco-plastic solids	Argillaceous rocks and mineral soils	Unified system (W.E.S. 1953)
	Organic soils	Radforth system (Radforth 1955, 1956)
Quasi-viscous solids	Snow	*
	Ice	*
Fluids	Water	—

*An appropriate classification has not yet been determined.

Surface Morphology: Macromorphology

Macromorphology is considered as the general surface configuration, including both the degree of slope and the slope form. In evaluating and mapping these elements the problems of scale and degree of generalisation are immediately introduced, and an arbitrary distinction has to be made between macromorphology and micromorphology. In the Petawawa study, the minimum slope segment which could be delimited at the mapping scale was 250 ft, and so larger slope segments were considered as macromorphology, whereas smaller features were treated as micromorphology.

The selection of class values for slope steepness and slope form (Table 2) was determined in part by the mapping requirements, and in part by vehicle performance—thus, 45° represents the maximum gradient for any current tracked vehicles, the shift from second to first gear takes place in wheeled vehicles around 26½°, and so on. Slope class values were determined from analysis of the air photos using a stereometer to measure the stereoscopic parallax, and the classification of slope form was based on careful stereoscopic examination of each slope segment. Even with the fairly wide range in the class interval, it was found necessary in the final mapping to make generalisations involving the combination of classes.

TABLE 2

Legend for terrain map (Fig. 1) and test courses (Fig. 3)

SURFACE COMPOSITION

- Consolidated rock — outcrops of granites and gneisses
- Non-consolidated material
- Mineral soil — poorly graded sands and silty sands, SP-SM Unified Soil Classification System
- Organic soil — fine and coarse fibrous muskeg, types 9 and 12 Radforth Classification System
- Water — water bodies more than three feet deep and one acre in area

SURFACE MORPHOLOGY: MACROMORPHOLOGY

Slope steepness:		Slope form:	
1	0 - 6° 0 - 10%	1	Convex, smooth
2	6 - 14° 10 - 25%	2	Planar, smooth
3	14 - 26½° 25 - 50%	3	Concave, smooth
4	26½ - 45° 50 - 100%	4	Convex, rough
5	Above 45° Above 100%	5	Planar, rough
6	Classes I and II	6	Concave, rough
7	Classes II and III	7	Classes 1 and 3
8	Classes III and IV	8	Classes 1, 2, and 3
9	Classes I, II, and III	9	Classes 4, 5, and 6

SURFACE MORPHOLOGY: MICROMORPHOLOGY

- Positive features of mineral soil in a random, linear pattern. Slopes 6 7, lengths 400 - 1800 ft, width-length ratio 1:4 - 1:20, amplitude 10 - 30 ft, spacing 10 per mile, non-symmetric sigmoid in section. Aeolian — fixed sand dunes
- Positive features of mineral soil in a random, linear pattern. Slopes 6 7, lengths 50 - 400 ft, width-length ratio 1:2 - 1:8, amplitude less than 10 ft, spacing 18 per mile, irregular sigmoid in section. Aeolian — sand sheets and ripples
- Negative features in mineral soil in a clustered, non-linear, overlapping pattern. Slopes 4 9, lengths 10 - 200 ft, width-length ratio 1:1 - 1:2, amplitude 10 - 50 ft, spacing 15 per mile, irregular cardioid in section. Glaciofluvial — kettle holes *
- Positive features of consolidated rock in a random, non-linear pattern. Slopes 5 5, lengths 20 - 100 ft, width-length ratio 1:1 - 1:2, amplitude 10 - 30 ft, spacing calculation not possible, irregular rectilinear in section. Glacial — rock outcrops and erratics *

* These symbols are not included in Fig. 1

SURFACE COVER: VEGETATION STUCTURE

	Height:	Stem type:	Form:
	More than 25 ft	Woody	Trees
Δ	5 - 25 ft	Woody	Young or dwarfed trees
	2 - 5 ft	Woody	Tall shrubs or dwarfed trees
	Less than 2 ft	Woody and non-woody	Low shrubs, grasses, sedges, and mosses

SURFACE COVER: VEGETATION SPACING (mean nearest neighbour distance)

9	0 - 10 ft	4	60 - 90 ft
8	10 - 15 ft	3	90 - 140 ft
7	15 - 25 ft	2	140 - 220 ft
6	25 - 40 ft	1	Greater than 220 ft
5	40 - 60 ft		

The field check revealed that almost all simple slopes without a tree cover had been correctly classified, but in the case of both simple and complex slopes under a tree cover, the steepness had been over-estimated in several cases and the slope form was frequently not identified.

Surface Morphology: Micromorphology

The detailed irregularities of the surface are probably of greater importance from the standpoint of ground mobility than the larger slope segments, because it is the micro features over which the vehicle actually travels. In the Petawawa study an attempt was made to identify all the small-scale surface features, and interpret some of the following characteristics: their composition, plan organisation, slope steepness and form, average length, width-length ratio, amplitude, cross section type, and genesis (Table 2). The scale factor prevented the mapping of such features individually, and so all that was attempted was the grouping of similar forms and the delimitation of the areas of occurrence of each type.

Micromorphology was found to be the most difficult of the factors to assess by air photo interpretation. This was in part a problem of detection: some features were too small to be resolved, while others gave such faint traces that they were very easily overlooked. There was also the problem of analysis: the

image did not provide sufficient information to permit identification of its characteristics. No surface detail could be discerned at all beneath the forest and bush cover, and even in the open areas it was often impossible to determine such characteristics as steepness and form, amplitude and cross section type which could mean the difference between a successful mission and immobilisation.

Surface Cover: Man-made Features

Man-made features need no specific comment. They were differentiated from natural cover features, because of the fact that they often have special significance in military operations. The photo interpretation of man-made objects is usually easy, because the feature and its characteristics are directly visible. In the Petawawa study, all the man-made objects were identified, with the exception of some trenches and foxholes, and some building foundations.

Surface Cover: Vegetation

Vegetation is important from two points of view as far as military vehicles are concerned — concealment and penetration. Concealment is affected by three factors: vegetation height, canopy closure, and seasonal changes. The height classes adopted in the Petawawa study are given in Table 2, and the vegetation was stratified into the four cover types by stereoscopic examination of the photos. A more refined subdivision was attempted initially, but it was abandoned because of the difficulties of distinguishing and mapping small differences in height for the shorter vegetation types and the irrelevance of further subdivision once the understorey space permits the passage of vehicles.

Canopy closure can be readily determined by photo interpretation and standard scales are available. Phenological effects cannot be assessed from a single set of photos, and so no attempt was made to indicate the seasonal variation of cover.

Penetrability was found to be more difficult to assess than concealment. Two factors are involved — the stem diameter, which is important because it determines the facility with which the tree can be overridden, and the stem spacing, which provides a measure of the impedance, either in the sense of the number of stems which must be overridden per unit of path length, or in the sense of the manoeuvrability limits in situations where the vegetation cannot be overridden. No satisfactory method of measuring stem diameters from the air photos was devised; attempts to relate crown width and D.B.H. were unsuccessful, and direct measurement of D.B.H. on the photos was not possible.

In contrast, the assessment of stem spacing was found to be quite feasible. The spacing class values (Table 2) were selected with vehicle manoeuvrability in mind, and the values were determined by making individual stem counts within circular sampling areas carefully positioned on the air photos so that all discernible variations of the forest cover were sampled. Mean nearest neighbour distances were calculated according to the spacing formula of Mills (1964): $x = 0{\cdot}57\sqrt{A/N}$, where x is the mean nearest neighbour distance, A is the ground area of the sampling plot, and N is the number of individual stems within the plot.

In concluding this section on the assessment of terrain factors from large-scale air photos, it should be noted that although a considerable amount of information about each terrain factor can be extracted from air photos at the 1 : 5000 scale there are definite limitations: firstly, the information derived from the photos does not provide any indication of seasonal changes, and yet in

Canada almost all attributes of a site vary with the season; secondly, at this scale it is difficult to retain an overall perspective, and to link up detail from one photo or flight line with another; thirdly, radical displacement can be a serious problem, especially when a short focal-length lens is used.

STORAGE AND PRESENTATION OF TERRAIN INFORMATION

The handling of any quantity of diverse information is always a difficult problem, especially when rapid retrieval is required. Two approaches, both with a mapping capability were investigated.

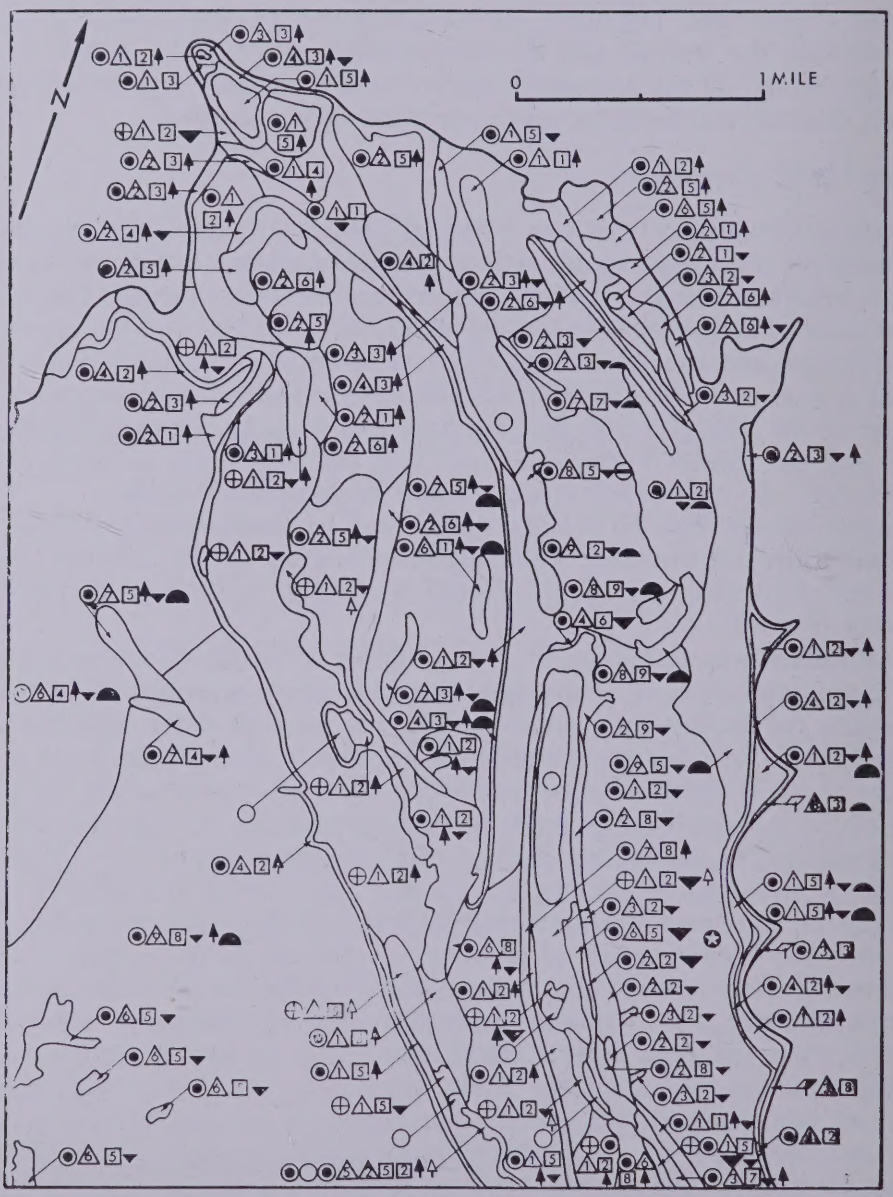

Fig. 1. Composite terrain map of part of Camp Petawawa, Ontario, Canada.

Both systems require the establishment of what may be termed fundamental terrain units. The surface in any area is an envelope, with a variety of inflections, and abrupt or gradual changes in composition. In nature the envelope is continuous, but it can be considered as a three-dimensional jigsaw puzzle, with the edges of the pieces determined by changes in either surface composition

or macromorphology. Each piece is, therefore, homogeneous with respect to composition and morphology within the limits of the class values established for these two parameters. Such pieces constitute naturalistic subdivisions of the surface, and provide the fundamental terrain units required.

Theoretically, it is possible to take this subdivision of the surface envelope even farther by considering all the other terrain factors in turn, and producing units which are homogeneous with respect to every parameter considered. In practice, however, this is not possible, because of the scale problem in mapping, and so information relating to the other terrain factors can only be serialised for each fundamental unit. A composite map of this type is presented in Figure 1. It should be noted that because of scale limitations, it was not possible to indicate what proportion of each unit was covered by each factor; the presence of a symbol simply indicates that a particular feature occurs within the unit. The total array of symbols is thus a useful summary statement of the conditions to be encountered within each unit, and the composite map serves as a convenient means of storage and retrieval for terrain information.

The second approach to the problem of data storage and presentation was an outgrowth of the composite map, and involved the use of an IBM 7044 computer for data manipulation and mapping. The whole system is automatic, apart from the input, which requires that the information is serialised in terms of the terrain factors as described in the previous section, keyed to the fundamental terrain units, and punched on cards. This constitutes the data bank. An additional set of cards is required to define the fundamental terrain units in terms of location and shape with reference to the rows and columns of the page format of the computer printer. This part of the procedure can be handled most effectively by computer-graphic equipment such as D-Mac XY digitizer, which converts cartographic input to digital form, but unfortunately this was not available and so the conversion had to be done graphically.

The production of a computer map requires the programme, a set of *condition* and *logic cards*, and both banks of data cards. The *condition cards* specify the attributes to be displayed, and have the form $v/o/c$, where v represents a particular variable or parameter, o represents one operator from the set $=$, $\neq$, $>$, $<$, and c represents the value or condition, with which the specified variable is to be compared. Any number of these *condition cards* can be included in one retrieval operation by inserting appropriate *logic cards* punched with either an *AND* or an *OR*. Thus a complex set of conditions can be specified.

The retrieval and mapping programme operates by scanning the cards of the data bank. If the attributes of any fundamental unit meet all the specified logical conditions, the number of this unit is stored in an array. Once the entire data bank has been examined and the array formed, the sub-programme to print the map is called. All the grid points are initially blank, and are changed to symbols only if they fall within the bounds of one of the fundamental units listed in the array.

A sample computer map is shown in Figure 2. This is a simple *Go–No Go* map of part of Camp Petawawa for a hypothetical wheeled vehicle. The vehicle characteristics, which must be expressed in terms that can be directly related to the data bank, are listed below together with a verbal statement of the *condition* and *logic* sequence required for the programme.

Non amphibious	Surface composition /=/ water
	AND
Ground pressure requirements greater than those afforded by organic terrain	Surface composition /=/ organic terrain
	AND
Maximum climb 50% grade	Macromorphology /></ 50% grade
	AND
Manoeuvrability requirements greater than 25 ft	Obstacle spacing /</ 25 ft

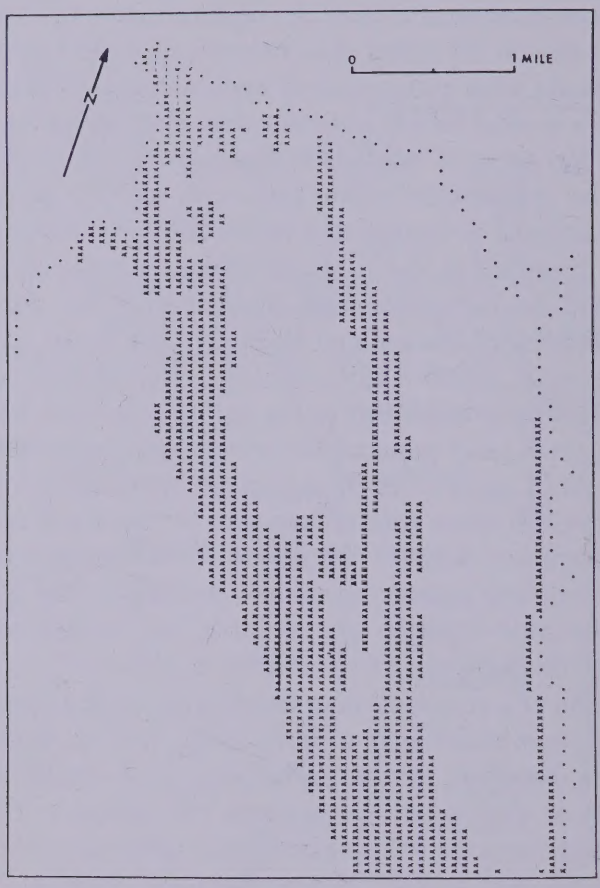

Fig. 2. Computer map of part of Camp Petawawa, Ontario, Canada.

It can be seen that the opposite of the required conditions was specified on each condition card. This was because the *No Go* areas were to be designated on the map. The programme involved the identification of all the fundamental terrain units which, for one reason or another, did not meet the vehicle requirements. Thus, the grid points within such units were printed with an *X*, while the areas where the vehicle could operate effectively remained blank.

There are certain problems inherent in the computer display of terrain data. With a computer of the type used in this project, output is via a line printer in the form of alphameric characters arranged in columns and rows. The page width is restricted to 13 in. (130 characters) and so for map output of large areas it is necessary to prepare the map in strips. There is no restriction in the other dimension since the paper is continuous.

Several quite serious problems arise out of the fixed dimension of the print characters ($\frac{1}{6}$ by $\frac{1}{10}$ in.). For example, in the study of Camp Petawawa where a

mapping scale of 1:25,000 had been adopted for the terrain factors, each character of the line printer covered approximately 400 by 200 ft (nearly 2 acres). It followed that any feature smaller than these dimensions could not be included save at the expense of an adjacent feature. In addition, boundary lines could not be shown accurately since the character representing any segment of the line can only be printed at the centre of each row-column intersection. This means that at the 1:25,000 scale the boundary position may be incorrect by up to 200 ft along one axis and 100 ft on the other, and the error is proportionally greater at smaller scales. Boundaries which do not parallel the rows or columns have to be shown as a series of steps, which makes the mapping of irregular areas very difficult. This is a serious problem in dealing with terrain factors in cross-country mobility since many features of critical significance such as rivers, bluffs, etc. are narrow and irregular.

TERRAIN UNITS AND VEHICLE SPEED

An attempt was made to test the terrain analysis system at Camp Petawawa in July 1967, when three vehicles, a jeep (M38A1), a three-quarter ton truck (M37), and an armoured personnel carrier (M113) were made available for a two-week period. The effects of terrain conditions on vehicle performances are very complex, and include a whole range of factors, such as vehicle design, which are quite beyond the scope of a study of this sort, and so the only performance factor considered was that of vehicle speed. A relationship between average speed and surface conditions can be expected from a purely empiric point of view, thus a legitimate approach in validating a terrain analysis system is the demonstration that differences in average speed actually occur in different terrain units; the more severe the terrain conditions, the worse the vehicle performance.

A series of fundamental terrain units were selected, which provided a good sample of conditions at Camp Petawawa. The units were grouped, so that in any particular group several terrain factors remained constant, while for the other factors there were differences of the order of one or two class intervals. The tests consisted of cross-country passes between starting and finishing lines. The driver made the decision as to his actual path as he went along, the only stipulations being that he maintain as straight a path and as fast a speed as possible. Vehicles were at full combat load, and in the case of wheeled vehicles, tyres were at 25% deflection. Times were taken with a stop watch, and distances were measured with a range finder or a chain, thus permitting the calculation of speed-made-good[1] for each pass.

In some terrain units only a single pass was attempted, since the problem was simply that of establishing whether the vehicle could climb a particular slope or not, or whether it could complete the pass without becoming immobilised. In other terrain units, ten passes were planned in order to obtain average speed-made-good and standard deviations; however, in a few instances the vehicle sustained damage or became immobilised, while in other cases the speeds-made-good were so similar over five or six passes that the full set of ten was considered unnecessary.

Space does not permit a complete analysis of the results (Fig. 3), but a few comparisons can be made. Courses 8 to 14 involved the ascent of terrace edges

[1]Speed-made-good: The average speed between starting point and destination, with distance being measured as a straight line between these two points.

where the surface composition was either loose, bare sand or sandy soil. None of the vehicles surmounted the slopes greater than 45° (class 5), nor the slopes in class 4 (26½°–45°) where the surface material was bare sand. However, the

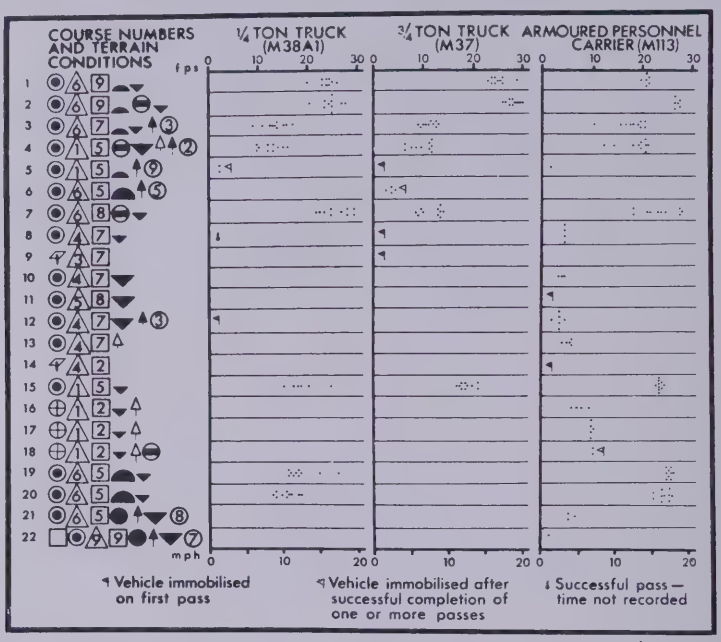
COURSE NUMBERS AND TERRAIN CONDITIONS
¼ TON TRUCK (M38A1)
¾ TON TRUCK (M37)
ARMOURED PERSONNEL CARRIER (M113)
fps
mph
Vehicle immobilised on first pass
Vehicle immobilised after successful completion of one or more passes
Successful pass — time not recorded

Fig. 3. Test courses and vehicle performance (legend for course descriptions is given in Table 2).

M38A1 was successful in course 8 (slope class 4 with a grass cover), where the maximum slope segment was 31°, and the M113 was successful on all the class 4 slopes even with a cover of bushes and trees (courses 10, 12, and 13): the range in average speed-made-good from 3·5 to 2·3 mph showing an inverse relation to the increase in steepness of the maximum slope segments from 28° to 35°.

Courses 17 and 18 were on enclosed muskeg, and were attempted only by the M113. The performance was very uniform, with average speeds-made-good of 6·9 and 7·1 mph. The immobilisation in course 18 resulted not from any undetected anomaly in the terrain, but from a man-made hazard in the form of a shell hole which had pierced the muskeg mat.

According to the terrain evaluation courses 1 and 2 were essentially similar; however, as can be seen in Figure 3, the vehicle performance figures were somewhat different (a t test showed that the differences were significant at the 1% level). This is an example of a situation where the occurrence of micromorphological features not discernible on the air photos produced an appreciable effect, particularly on the performance of the M113.

The introduction of another variable, that of vegetation in course 3, produced a marked effect, as can be judged from the differences in mean average speed between courses 2 and 3: M38A1—16·9 mph and 11·6 mph; M37—19·1 mph and 7·6 mph; M113—18·7 mph and 12·4 mph.

The conditions on courses 4, 5, and 15 were similar apart from the density of vegetation. As can be seen from Figure 3 there was a direct relationship between the average speeds of all three vehicles and the differences in vegetation density for the three courses.

Courses 19 and 20 make an interesting comparison because the vehicles traversed the same terrain unit, but in different directions. The micromorphology consists of a series of fossil dunes (some of which are currently active), which

form a broad U-shaped belt. In course 19 the vehicles made their way between the arms of the U and across the dunes at the point corresponding to the basal segment of the U, while in course 20 they were required to pass obliquely across both series of dunes forming the upper limbs of the U. The slight differences in average speed, 17·9 mph and 17·0 in the case of the M113 (significant at the 1% level), demonstrate the very direct controls which terrain conditions exert on vehicle performance.

The vehicle tests at Camp Petawawa demonstrated some of the weaknesses in the system of terrain analysis which have been discussed in the preceding pages, specifically in the matter of micromorphology. However, tangible relations between vehicle performance and terrain conditions as abstracted by the system were obtained and so attempts are now being made to refine the procedures. As Bekker (1960) has aptly commented, 'present knowledge of off-the-road locomotion may be compared to the knowledge of principles of aeronautics available in the early nineteen hundreds'. Much basic research in terramechanics has yet to be done, and some of the most serious deficiencies are in the assessment of ground conditions.

REFERENCES

BEKKER, M. G. (1960). *Off-the-road Locomotion.* (University of Michigan Press: Ann Arbor.)

GADD, N. R. (1963). Surficial geology of the Chalk River area, Ontario-Quebec, Canada. *Geological Survey of Canada,* Map 1132 A.

GILLESPIE, J. E. (1964). Soil survey of Renfrew County, Ontario. *Ontario Soil Survey Report* No. 37.

MILES, R. D. (1963). A concept of landforms, parent materials and soils in air photo interpretation studies for engineering purposes. *Int. Arch. Photogramm.* **14**, 462–77.

MILLS, H. L. (1964). *The physiognomy of vegetation: a quantitative approach to vegetation geometry based upon the structural cell concept as the minimum sample size.* U.S. Army Engineer, Waterways Experiment Station, Corps of Engineers, Vicksburg, Mississippi. Contract DA 22-079-eng332-Marshall University, Huntington, West Virginia.

RADFORTH, N. W. (1955). *Organic terrain organization from the air.* Handbook No. 1. Report No. PR 95. Defence Research Board, Department of National Defence, Canada.

RADFORTH, N. W. (1958). *Organic terrain organization from the air.* Handbook No. 2. Report No. 124. Defence Research Board, Department of National Defence, Canada.

WATERWAYS EXPERIMENT STATION (1953). *The unified soil classification system.* U.S. Army Engineer Tech. Mem. No. 3-357. Waterways Experiment Station C.E. Vicksburg, Mississippi.

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